Using *ENERGY-10*
to
Design Low-Energy Buildings

by

J. Douglas Balcomb
National Renewable Energy Laboratory

A general overview of the *ENERGY-10* design-tool computer program with example results

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ABSTRACT

A major barrier to using energy simulation tools during the design process of a building has been the difficulty of using the available programs. The *ENERGY-10* program overcomes this hurdle by automating many of the time-consuming tasks, shortening the time required from hours or days to minutes. Building descriptions are created automatically based on defaults. The APPLY and RANK features speed the process of comparing the performance of energy-efficient strategies by automatically modifying the building description and sequencing the operations. Evaluations are based on hour-by-hour simulations of both daylighting and thermal performance. Graphical output greatly aids the process of assimilating and understanding the results. This paper describes the program's features, simulation engines, the associated design guidelines book, and the workshop training program. Results are presented for a 6500 sq ft office building in Missouri.

Introduction

We are now seeing the emergence of a new generation of compute-based energy design tools. These tools focus on the user interface and offer the opportunity to get quick and simple estimates of energy performance in the early design phase yet harness the full power of detailed hourly simulation to accurately capture interactive effects. A new aspect of these tools are also that they try to view the energy performance in a holistic perspective, that is, they include other performance criteria such as daylighting, comfort, economic and environmental considerations. *ENERGY-10* epitomizes this new generation of tools and is the first to obtain wide distribution in the United States.

ENERGY-10 is not just software—the accompanying book, *Designing Low-Energy Buildings,* provides guidance in the application of each of the highlighted strategies and serves as an important tool in both university courses and training workshops, where the program has seen its greatest impact. Emphasis was placed on the front end and the back end—the user interface and the output graphics—because these areas had been neglected in other tools.

Impact

First released in June 1996, *ENERGY-10* has enjoyed good acceptance by the design and consulting audience that it targets. As of September 1999:

- 1160 *Designing Low-Energy Buildings with ENERGY-10* packages have been sold.
- 32 two-day workshops have been presented with an average attendance of 20.
- 8 workshops are scheduled throughout the United States for Sept–December 1999.
- 23 seminars have been presented is a wide variety of forums.
- Site licenses have been purchased by 40 colleges and universities where the *Designing Low-Energy Buildings with ENERGY-10* package is being used as the teaching tool in architectural and engineering courses. This use of the tool has been particularly effective.

A survey conducted in the spring of 1998 by the Passive Solar Industries Council (PSIC); who are contracted to provide distribution, user support, and training; found that

- The predominant number of users are architects (37%), followed by engineers (18%) and energy analysts (17%)
- Many are academics (19%), students (18%), and project managers(7%)
- The program is most commonly used to analyze residences (by 75% of users), offices (by 54% of users), assembly buildings (by 18% of users), warehouses (11% of users), and an assortment of other commercial and institutional building types.
- 29% have used the program on more than 10 projects, 17% on 6 to 10 projects, and 40% on 2 to 5 projects
- 58% find the program more technically successful that other building evaluation software they have used
- 63% find the program more user friendly than other building evaluation software they have used.

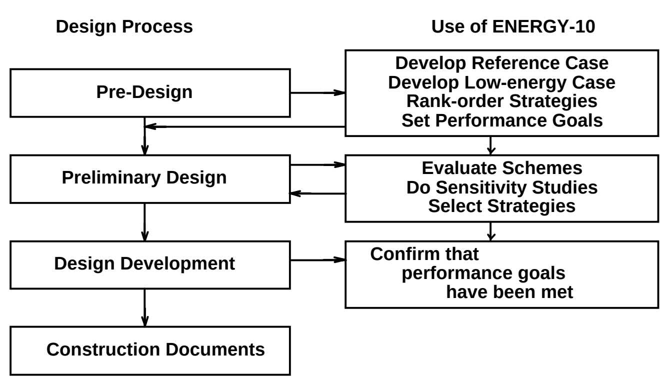
Designing Low-Energy Buildings with ENERGY-10 received a Progressive Architecture award for research.

Approach

The two main philosophies embodied are the *whole-building or integrated design* approach and the importance of the *early design stage.* The whole-building or integrated design approach emphasizes the need to take many different design aspects into account, as opposed to traditional design where only a few aspects are considered and optimized. *ENERGY-10* facilitates the quick evaluation of various strategies by automatically applying and rank ordering those desired. In the current release the 12 strategies shown in bold are implemented:

Daylighting	**Energy-Efficient Lights**	**Glazing**
Passive Solar Heating	**Shading**	**Insulation**
Thermal Mass	**Air Leakage Control**	**High-Efficiency HVAC**
HVAC Controls	**Economizer Cycle**	**Reduced Duct Leakage**
Photovoltaics	Natural Ventilation	Evaporative Cooling
Exhaust-Air Heat Recovery	Solar Air Preheat	Solar Water Heating

Photovoltaics will be completed in fall 1999. The strategies not shown in bold are planned.



ENERGY-10 compliments the design process, providing the right information at the right time. Experience has shown that the most critical phase is pre-design. *ENERGY-10* was designed to be particularly effective in the early stages when the information is most valuable.

While the traditional approach typically concentrates on initial costs and aesthetics, the integrated design approach performs simultaneous evaluation of the interaction of heating, cooling and daylighting. The program automatically calculates the required sizes of HVAC equipment so this important tradeoff is included in the evaluations.

Smooth and easy integration of energy efficiency in the early design phase was a prerequisite of *ENERGY-*

10. This was based on the observation that the traditional available programs for thermal and daylighting evaluation were so difficult to use that they were only being employed late in the design process—when it was too late to significantly affect the end product. However, the program is also quite useful in later design phases. The figure shows the intended use of *ENERGY-10* during the evolution of the design process.

ENERGY-10 is targeted to buildings less than 10,000 square feet (hence the name). This size category constitutes about 76% of all commercial buildings and 22% of commercial building floor space in the United States.

The program requires only 5 inputs to start the simulation and analysis process:

- geographic location (from 239 sites)
- total floor space
- intended building use (from a list of nine)
- number of stories
- type of heating, ventilation and air conditioning (HVAC) system (from a list of 12)

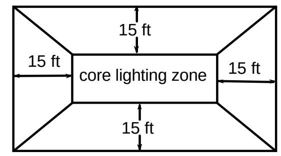
From these basic inputs, *ENERGY-10* automatically creates two simple "shoebox" buildings: one is a reference building that emulates a building constructed using standard design practices; the other is a low-energy building that incorporates a number of energy-efficient options. Each shoebox may have up to two thermal zones. All variables excluding the five parameters mentioned above, are defaulted to reflect typical construction practices. These variables include materials and constructions, windows and doors, and schedules of internal gains. All variables can be edited subsequently. It is also possible to change all the default parameters. Within just a few minutes, the user can be studying detailed results that identify the primary energy issues of his or her building and sort out the most effective strategies that can be used to save operating energy or operating costs. A example of the evolution of a project is presented at the end of the report.

As the design process evolves, the user edits the building descriptions to represent the building as it becomes more complex. Walls and roof planes can be added as the design becomes more articulated. As the design proceeds, the building descriptions become more detailed and more representative of the building being designed and less like the original shoe box.

The Simulation Engines

Thermal analysis uses the California Nonresidential Simulation Engine (CNE) written by the Berkeley Solar Group (BSG), which employs a multizone, thermal-network solution (Wilcox et al, 1992). CNE has been validated using the BESTEST protocol adopted by the U.S. Department of Energy (DOE). The Lawrence Berkeley National Laboratory (LBNL) has been fully responsible for all the daylighting aspects of *ENERGY-10*. The daylighting simulation engine incorporates the split-flux routine used in the DOE-2 computer program (Winkelmann and Selkowitz, 1985), which is also used in LBNL's Building Design Advisor. This technique is suitable for evaluating daylighting from windows and skylights. CNE integrates the detailed hour-by-hour daylighting calculation with a subsequent thermal evaluation. Thus the reduction in heat into the building as a result of dimming the lights is properly accounted in the thermal loads.

Daylighting



During the setup of daylighting for a shoe box geometry, the program automatically creates five lighting zones in each thermal zone, as shown in the schematic, including complete geometrical descriptions of each window and interior wall surface (if the building is narrower than 30 ft, one zone is created).

The simulation program first calculates daylighting illuminance at a control sensor location for each of 20 sun angles for each aperture. Using these results, illuminance values are then calculated for each hour for each lighting zone.

The reduction in artificial lighting is calculated based on either a continuous-dimming or stepped control algorithm.

For more complex geometries, the user *may* enter the surfaces, aperture locations, and control characteristics of each lighting zone up to a maximum of 10 for each thermal zone. However, this process is tedious and error-prone because it is not yet automated and the 3-dimensional coordinates of each element must be specified. In practice, most users prefer to utilize hourly daylighting results calculated for rectangular geometries in conjunction with thermal calculations made for the complex building. Experience has shown that the errors incumbent in this approach are second-order and acceptably small. A few users undertake the more accurate approach. In any case, *ENERGY-10* is not a daylighting design tool—the purpose of the simulations is simply to estimate the savings due to dimming and to capture the thermal effects of daylighting.

Thermal Analysis

ENERGY-10 automatically creates the input file for the CNE thermal simulation engine based on the building parameters in the dialog boxes. The simulator then transforms the building description into a thermal network model. The thermal network solver uses 15-minute time steps (for numerical accuracy) and iterates to find an energy balance at every step, accounting for heat storage in each material layer. A rigorously enforced energy balance is important for accurate simulation of highly interactive strategies used in good passive design.

Twelve HVAC systems options can be simulated in Version 1.2. A key feature of the CNE simulation engine is that it iterates to find a consistent solution of the loads and systems calculations, a feature not found in most United States thermal simulation programs. The systems are:

HVAC System	Heating System	Cooling System	Air Distribution
Air Source Heat Pump/ER Backup	HP/ER Backup	A-A HP	Forced Air
Baseboard Electric Heat	BB Electric	none	none
DX Cooling with Elect Furnace	Electric Furnace	DX	Forced Air
DX Cooling with Gas Furnace	Gas Furnace	DX	Forced Air
Gas-Fired Unit Heater	Gas/Radiant	none	none
Heat & Vent with Elect Furnace	Electric Furnace	none	Forced Air
Heat & Vent with Gas Boiler	Gas Boiler	none	Forced Air
Heat & Vent with Gas Furnace	Gas Furnace	none	Forced Air
PTAC AA HP with ER Backup	HP/ER Backup	DX	Thru the Wall

PTAC with ER BB Heat	BB Electric	DX	Thru the Wall
PTAC with ER Heat	Electric Coil	DX	Thru the Wall
PTAC with Gas Boiler & HW Coil	Gas Boiler/HW Coil	DX	Thru the Wall

These are the systems used in more than 95% of all residential and small commercial buildings.

Automatic Ranking.

A common use of building simulation programs is to rank the effectiveness of various energy efficient strategies (EESs) being considered. This time consuming process is automated in *ENERGY-10*. The RANK feature is similar to APPLY except that the EESs are applied individually rather than in combination. When the user selects a set of EESs and then clicks on RANK, the program applies the first EES, performs a simulation, saves the results, removes the EES, applies the next EES, and so forth until all the EESs have been applied and simulated. The program then ranks the results according to any of several desired criteria (lowest annual energy, lowest annual operating cost, etc.) and displays the results.

Automatic HVAC Sizing

A key feature of *ENERGY-10* is called AutoSize. AutoSize calls CNE to compute the rated capacities of HVAC equipment required to meet winter and summer design-day loads. When enabled, which is the default, this calculation happens automatically prior to any simulation. All the complex interactions that occur are properly accounted. For example, the reduction in fan operating energy associated with using better windows is evaluated. The RANK operation takes account of such interactions.

It is well known that the added cost of an energy-efficient building need not exceed that of a conventional building because the cost of other upgrades (insulation, windows, high efficiency equipment, shading, etc.) can be paid out by money saved from the reduced cost of installing smaller HVAC equipment. This interaction makes it imperative to get early and accurate estimates of required HVAC rated capacities to serve as the basis for justifying other energy efficient strategies. Properly done, the result is a building that requires far less energy to operate yet costs no more to construct. The hang-up in achieving this result has usually been the added cost of design. With *ENERGY-10*, this barrier has been lowered.

Units

Users have a choice of five systems of units, USA, metric (energy in kWh, Cal, or Joules) and SI.

Help

ENERGY-10 incorporates an extensive and comprehensive Help that supplants the need for a user manual. This facility has received acclaim from many users. It incorporates a graphical approach that pops up descriptions from dialog boxes. Help also includes a wealth of user advice, exercises to assist users in learning the program, and graphical representations wherever possible.

Workshops, Training, and User Support

Designing Low-Energy Buildings is used in a workshop environment in conjunction with the *ENERGY-10* program. PSIC conducts two-day workshops to help designers understand the issues of energy efficiency and provide them with a suitable analysis tool. The workshop agenda alternates between lectures that describe design techniques and hands-on use of the *ENERGY-10* program at computer terminals. Four workshops were given in 1997, 16 in 1998 and the total for 1999 will be 23 workshops. These are held at facilities with computer labs, often on campus. Nine instructors have been certified by PSIC to present workshops and seminars.

PSIC maintains a hot line and compiles a list of user complaints, problems, and suggestions. Users have been generally quite satisfied but want more features. The feedback has been invaluable for understanding how the program is used and how it can be modified to be more effective. *ENERGY-10* users tend to be small architectural firms or consultants that have not historically used building simulation. Typically it takes them 2 to 4 days to become reasonably proficient with the program.

One problem reported is that some users object to having to do take-offs on their plans. It is extremely easy to get started with a shoe-box design because the process is automatic. However, progress slows during the preliminary design phase, when the actual building design must be described to the program. The user must compute wall, roof, and window areas and enter these numbers into the appropriate dialog boxes. The time and numerical detail required for these tedious calculations is perceived as a barrier. Users would prefer an automated procedure for calculating and conveying this information. The proposed solution is to provide a graphic input routine (called *Sketch*) that would allow the user to draw the building on the screen using the mouse. The program would then compute the necessary building areas, etc. required by *ENERGY-10* for the analysis. It is a daunting challenge to develop this graphic input module, but work has been started on it. *Sketch* should be fully integrated into *ENERGY-10* in 2000. This will account for site shading by trees and neighboring buildings and also facilitate description of the daylighting geometry inside the building.

Photovoltaics

Work is well along to add photovoltaics (PV) as a new strategy in *ENERGY-10*. The benefits are: (1) users who had not been considering PV can easily evaluate its performance, (2) PV users who use *ENERGY-10* for their analysis will be likely to improve the rest of the building design, and (3) the evaluations will be more integrated with other strategies than those done with stand-alone programs. This is because the hourly electric load calculated by *ENERGY-10* not only accounts for electric demand schedules but also for HVAC electric use in response to weather and occupancy and dimming of lights as a result of daylighting. TRNSYS will be used as the simulation engine for PV.

The PV EES will be implemented to define all the parameters required to simulate a PV system. The APPLY operation will automatically make changes in the building description to add a PV array, the associated conversion and battery storage systems (if desired), thermal connections to the building, control algorithms, and special electric tariffs. The user will define these in the PV Characteristics dialog box.

The peak-shaving benefit of a PV array will be determined during the simulation. Since the peak is usually on a hot, clear summer afternoon, the PV system will be operating at its peak. This can easily double the cost-effectiveness of an installation in areas where electric utility peak-demand charges are high.

The first phase of the PV development is expected to be complete by the end of 1999.

Conclusions

Designing Low-Energy Buildings with ENERGY-10 was written to fill an identified need and has been well received by designers and energy consultants. It is fast, easy to use, and accurate. It allows the user to quickly identify cost-effective energy-efficient strategies based on detailed hourly simulation analysis that accounts for interactive effects. With care a design team should be able to develop a building that uses about 50% as much energy as a typical building yet costs no more to build, provides a better working and living environment, and accounts for less than ½ the emissions of CO_2/SO_2/NO_x of a typical building. Many cases of such buildings exist. For a good example, see http://www.light-power.org/harmonylib/index3.htm on the internet. This describes the Harmony Library in Ft. Collins, Colorado, a beautiful 30,000 building.

Acknowledgments

Funding for *Designing Low-Energy Buildings with ENERGY-10* is from the U.S. DOE. The Program Manager is Mary-Margaret Jenior, Office of Energy Efficiency and Renewable Energy. Programming of *ENERGY-10* was done at NREL, at LBNL, and at BSG. NREL conceived the program, programmed the front end, and has managed the development effort. LBNL was responsible for the daylighting portions of the program, including the daylighting simulation engine, and providing technical advice on all aspects. BSG developed the thermal simulation engine and programmed the output graphics. PSIC developed the guidelines book, *Designing Low-Energy Buildings*.

Designing Low-Energy Buildings with ENERGY-10 is distributed by PSIC. The cost is $250 or $50 for full-time students. These funds are used by PSIC to help offset the cost of user support. Descriptions are available on the internet at http://www.psic.org and http://www.nrel.gov/buildings/energy10.

References

Wilcox, B. A., J. R. Barnaby, and P. W. Niles, CNE Users Manual, Berkeley Solar Group, Oakland, CA (1992).

Winkelmann, F.C. and S Selkowitz, Daylighting Simulation in the DOE-2 Building Energy Analysis Program, Energy and Buildings, 8 (1985) 271-286.

Example: Columbia Savings & Loan

This appendix presents an example of the use of *ENERGY-10* in a design process. The building is a 6500 ft^2 office building located in Columbia, Missouri, a climate with higher heating and cooling loads than the United States average. The design evolves from the shoeboxes of the pre-design phase through a preliminary design.

The example illustrates the following key features of *ENERGY-10*:

AutoBuild. Two complete building descriptions are generated automatically; a reference case and a low-energy case, based on only five key characteristics known in predesign. The reference case is a basic rectangular shoe-box building that satisfies the building requirements and has all the attributes of the building to be designed, such as appropriate internal gain schedules, glazing-to-wall ratio, and constructions. The low-energy case is the same building but modified to incorporate a set of energy-efficient strategies (EESs).

Less than 15 minutes after starting a new project, the user can be studying these results.

APPLY. This feature facilitates the incorporation of any or all of the 12 energy efficient strategies (EESs). The user first selects any set of desired EESs from a menu and then clicks on APPLY. The program creates a complete new Bldg-2 by modifying Bldg-1 according to a prescription. For example, if the Insulation EES is selected, all of the walls in the building might be changed from a 4-inch steel-studs (R-9) to 6-in steel-stud construction with a 2-in foam sheathing (R-19), the roof changed from R-19 to R-38, and the perimeter insulated with 2 in of foam. The user gets to specify exactly what changes will be made. (APPLY is used automatically during AutoBuild to create the original *low-energy case* starting from the *reference case*.)

Side-By-Side Comparisons. Two building descriptions, Bldg-1 and Bldg-2, are carried in the database at all times, facilitating comparisons. Initially used for the two shoe boxes created by AutoBuild, these two buildings can subsequently be used to compare the performance in two climates, the effect of a single change, or the effect of multiple changes.

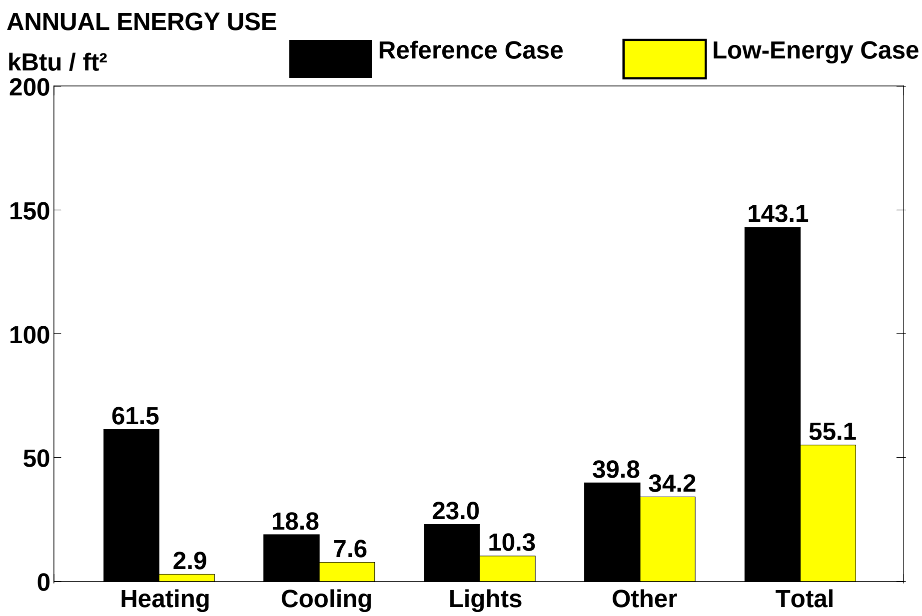
Summary Information. A handy one-page tabular comparison Bldg-1 and Bldg-2. This does not present all the detail of the building descriptions, but contains the most relevant data, including selected results.

Graphic Output. Twenty graphic outputs are available that compare the Bldg-1 results with Bldg-2 results. Bar graphs, such as the graph on the next pages, compare overall loads, costs, and cost breakdowns by end use. Line graphs show monthly loads, daily-average profiles for each month, daylighting effectiveness, and actual hourly results for any period. Bar-graph comparisons of a selected sequence of design schemes can be displayed. All graphical results can be printed directly or copied to the Clipboard as metafiles for inclusion in a report. This feature was used in the writing of this report—all of the graphs were copied directly from *ENERGY-10* and then edited slightly for style. These graphs can be used to educate the client and to demonstrate the value of good building design.

RANK. As described previously.

KEEP. As a design progresses, a series of different variants are created and saved. These typically start with the AutoBuild shoeboxes and evolve to a preliminary design, perhaps through several candidate schemes. KEEP provides a way to save the results of each desired variant in a separate file that can be plotted in a bar graph to illustrate the results of the design progression.

Pre-Design Results



Building performance before and after 12 energy-efficient strategies are applied in *combination.* This pair was created automatically during AutoBuild. The characteristics of the *Reference Case* and *Low-Energy Case* buildings are given in the Summary Information table on the next page. The *Low-Energy Case* was created by using the APPLY operation with all 12 strategies selected. The prescription for what happens when each strategy is applied is defined by the user. In this case, the original defaults were used. In this graph "other" includes hot water, fan energy, and plug loads—the reduction is due to decreased fan energy.

Results from the simulation of these two buildings give the designer two important pieces of information:

1. They show the energy use pattern of a typical building of the desired size, in the right climate, having the appropriate internal gains for a building of the desired type. The balance between heating, cooling, and other energy uses is determined.
2. The simulations identify the potential for energy and cost savings from a particular set of strategies.

Pre-Design Results / Summary Information

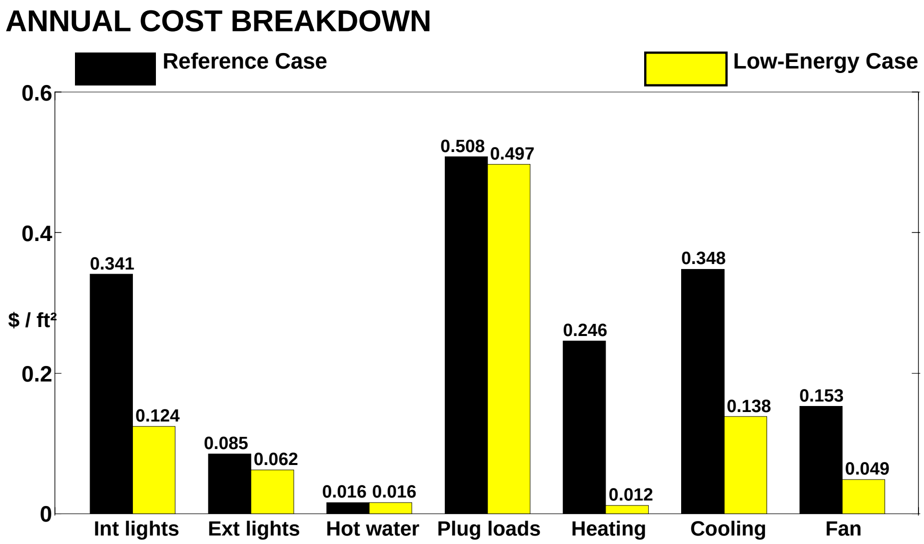
Columbia Savings & Loan Weather file: Columbia.et1

Description:	**Reference Case**	**Low-Energy Case**
Floor Area, ft²	6500.0	6500.0
Surface Area, ft²	17278.8	17278.8
Volume, ft³	84500.0	84500.0
Total Conduction UA, Btu/h-F	1803.1	753.5
Average U-value, Btu/hr-ft²-F	0.104	0.044
Wall Construction	steelstud 4, R=8.1	steelstud 6 poly, R=19.2
Roof Construction	flat, r-19, R=19.0	flat r-38, R=38.0
Floor type, insulation	Slab on Grade, Reff=21.9	Slab on Grade, Reff=98.7
Window Construction	4060 double, alum, U=0.70	4060 low-e al/b, U=0.31
Glazing name	double, U=0.49	double low-e, U=0.26
Window Shading	None	40 deg latitude
Wall total gross area, ft²	4279	4279
Roof total gross area, ft²	6500	6500
Ground total gross area, ft²	6500	6500
Window total gross area, ft²	1056	1080
Windows (N/E/S/W:Roof)	13/9/13/9:0	7/3/24/3:8
HVAC system	DX Cooling with Gas Furnace	DX Cooling with Gas Furnace
Rated Output (Heat/Cool), kBtuh	386/358	157/230
Rated Air Flow, cfm	10741	6851
Heating thermostat	72.0 °F, no setback	72.0 °F, setback to 67.0 °F
Cooling thermostat	76.0 °F, no setup	76.0 °F, setup to 81.0 °F
Heat/cool performance	eff=80,EER=8.9	eff=90,EER=13.0
Economizer?/type	no/NA	yes/fixed dry bulb, 60.0 °F
Duct leaks/conduction losses, total %	11/10	3/0
Peak Gains; IL,EL,HW,OT; W/ft²	1.78/0.33/0.26/1.52	1.33/0.25/0.26/1.52
Added mass?	none	3250 ft², 8in cmu
Daylighting?	no	yes, continuous dimming
Infiltration, in²	ELA=569.1	ELA=154.0
Results:	Energy cost: 0.400 $/Therm, 0.054 $/kWh, 2.470 $/kW	
Energy use, kBtu	930302	358328
Energy cost, $	11031	5842
Saved by daylighting, kWh	NA	13261
Total Electric, kWh	147862	91698
Internal/External lights, kWh	35135/8769	13097/6577
Heating/Cooling/Fan, kWh	0/35882/15737	0/14559/5127
Hot water/Other, kWh	0/52338	0/52338
Peak Electric, kW	61.6	29.0
Fuel, hw/heat/total, kBtu	26313/399440/425754	26313/19114/45428
Emissions, CO2/SO2/NOx, lbs	208338/1173/612	126621/725/377

Note the dramatic reduction in HVAC capacities required to meet peak winter and summer design-day loads (about 36%). The money saved by these reductions might well be sufficient to pay for the added cost of all the other upgrades, resulting is a building that costs no more to build yet uses 61% less energy with a reduction in annual operating cost of 47%.

The last line, emissions, refers to the annual emissions that result from building operation. It includes on-site emissions, such as CO_2 resulting from the burning of natural gas, and off-site emissions at the power plant that provides electricity to the building. The coefficients used for these calculations are based on national average value; however, a user could specify local values if these are known. Although embodied energy and other environmental impacts due to building construction are important, the cumulative impact due to building operation over many years is usually several times greater.

Pre-Design Results / Breakout of Costs by End Use



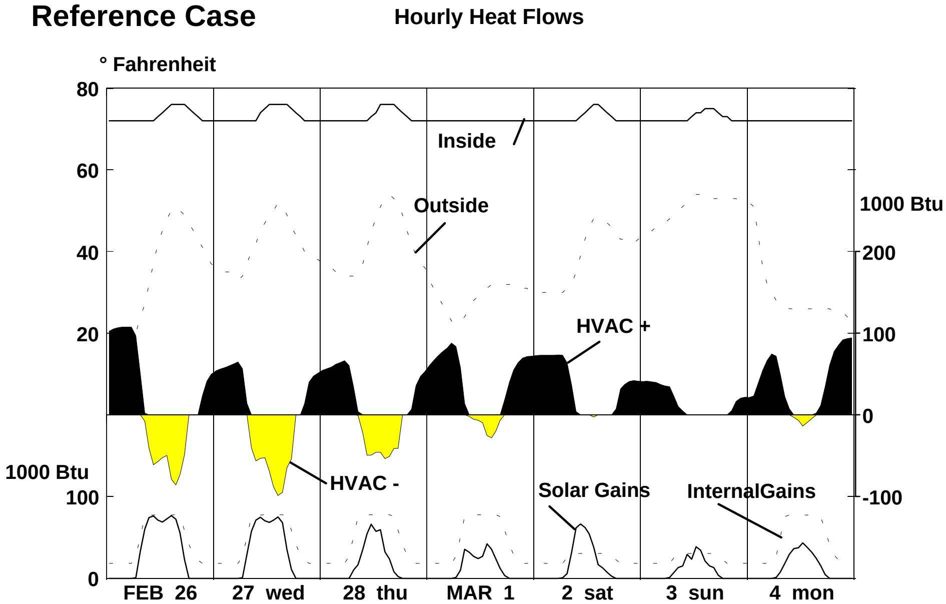
This plot allows a user to better understand the causes of the annual utility costs. The total costs are \$1.70/ft^2 for the references case and \$0.90/ft^2 for the low-energy case (which can be seen in another plot not shown here). It is clear in this situation that reductions in plug loads would be required to affect significantly further reductions in the total cost of the low-energy case.

Heating and hot water use fuel and the other categories use electricity. The plug load energy use for the two cases is identical (8.05 kWh/ft^2). The reason for the difference is cost is because demand charges are calculated separately for each electric use.

Internal gain schedules and peaks are based on defaults tabulated by the Energy Information Agency for offices and represent national averages. Uses can change either the hourly schedule of use or the peaks.

Note that the cost of running the air-distribution fans is very significant. The major reduction seen is because the air flow is reduced, the fan is more efficient, and the time it is operated is less. Insights such as this are a valuable part of displaying the *ENERGY-10* results.

Pre-Design Results / Hourly Heat Flows



This shows hourly heat flows for 7 days. The user can quickly scroll through the entire year. One to 14 days can be displayed on the plot. The user can click on peak+ or pead- to jump to the annual peak heating or cooling.

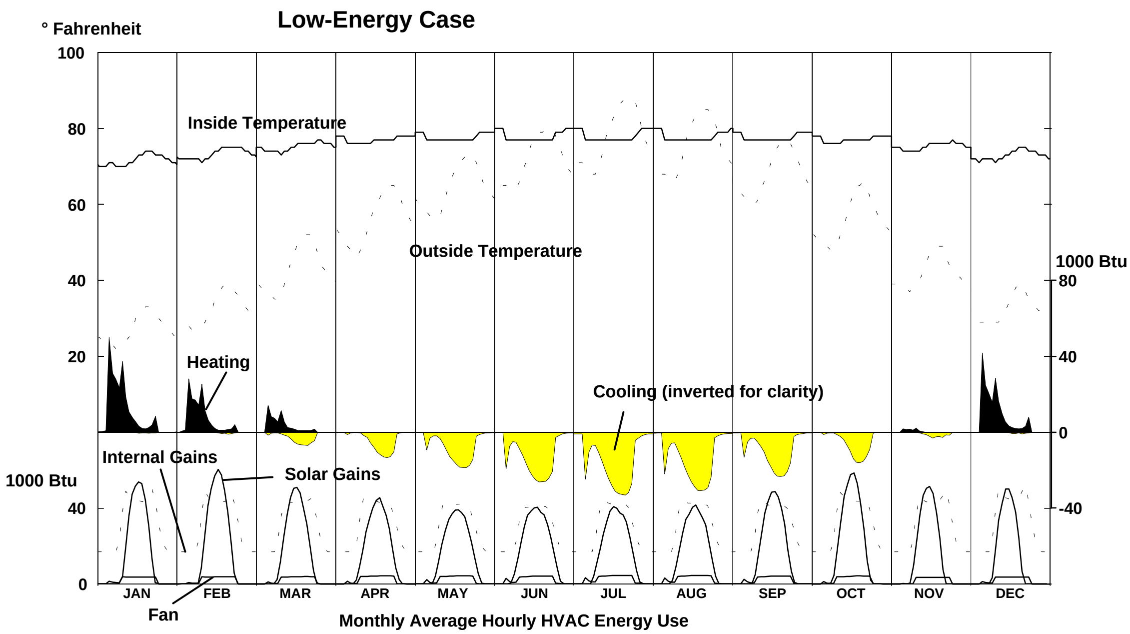
The upper heat flow, shown black (HVAC+) is heating out of the HVAC system.

The lower heat flow, shown lighter (HVAC-) is cooling out of the HVAC system and is shown inverted for clarity. The values shown in this time period are primarily due to daytime ventilation of 975 CFM.

This plot can be shown for either building, as shown here for the low energy case. or simultaneously, to show a comparison.

Similar plots can be made for energy use and for daylighting.

Pre-Design Results / Typical Hourly Energy Use for Each Month



Energy use by time of day for each month. This shows the result of averaging the all the days in a month for each hour. It clearly shows the typical behavior, both daily and annually. The temperature curves are not continuous because the averages for each month are displayed independently.

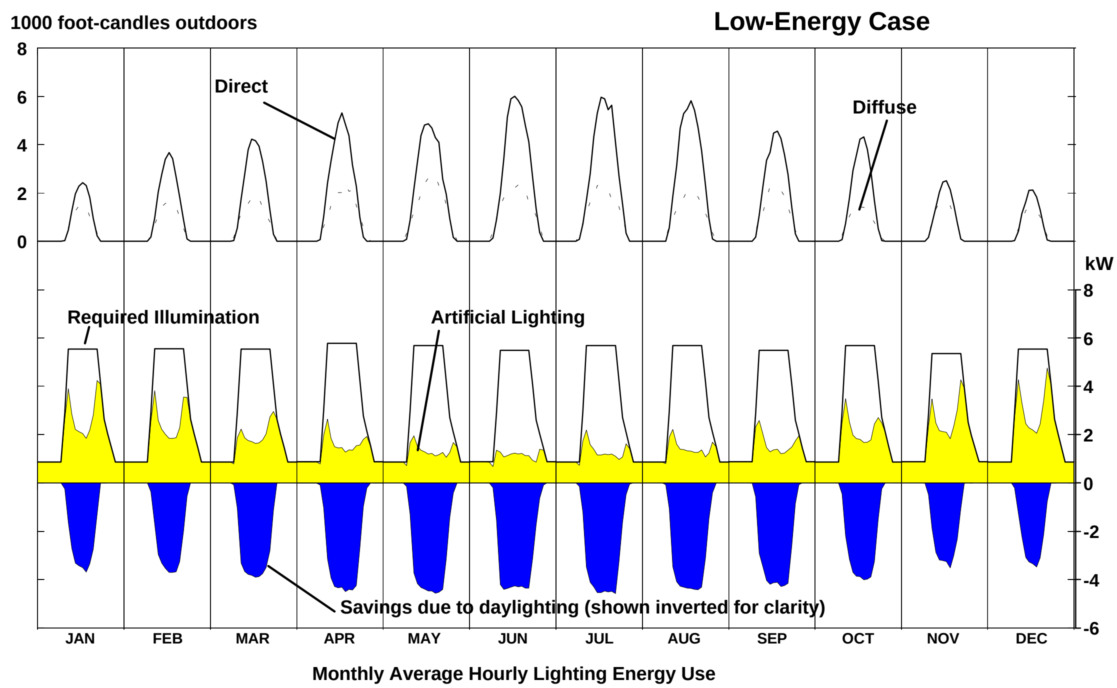
Note the pronounced effect of setup from night setback in the winter and setback from night setup in the summer.

Note the enhanced solar gains in winter—a result of passive solar heating (locating most windows on the south) and the greatly reduced daytime heating loads due to the combined effect of solar gains and internal gains.

This plot can be shown for either building, as shown here for the low energy case or simultaneously, to show a comparison.

Similar plots can be made for loads and for daylighting.

Pre-Design Results / Daylighting



This shows the result of averaging the all the days in a month for each hour. It shows the typical behavior, both daily and annually. Saving in the summer are about twice those in winter because there is more sun and because the days are longer. Another plot, not shown here, displays the monthly totals.

The strategy employed is continuous dimming, which is the default. Saving here are limited because some lights are left on at night, which is typical for an office.

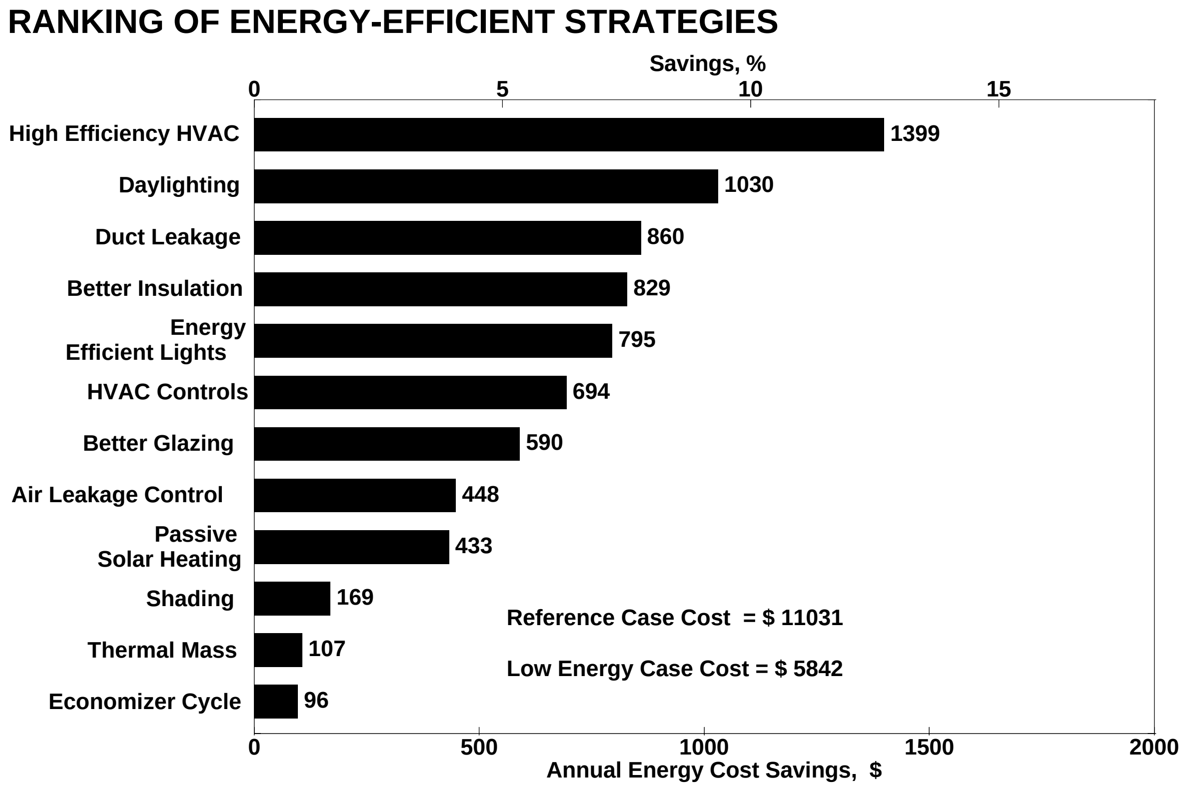
Artificial lighting is reduced from 35 MWh in the reference case building to 13 MWh in the low energy case, which contributes in a major way to the reduced cooling loads.
9 MWh of the saving are due to energy efficient lights and 13 MWh are due to dimming.

Although not done in this example, it is possible for the user to account for daylighting when doing AutoSize of HVAC equipment. To be conservative, the default is *not* to do this.

This plot can be shown for either building, as shown here for the low energy case, or simultaneously to show a comparison.

Similar plots can be made for loads and energy use. Scrollable hourly plots for one to 14 days can also be displayed.

Pre-Design Results / Ranking



In this plot energy-efficient strategies are ranked by annual cost savings.
There are 9 other options, such as annual energy use savings, heating energy, etc.

In a RANK operation each strategy is applied *individually* and simulated. The purpose is to provide an early estimate of the relative effectiveness of each strategy. To apply strategies in combination, the APPLY operation should be used.

An important thing to note is that this entire operation is automatic in *ENERGY-10*. Otherwise, this process would be very tedious and time consuming. When the user selects a set of EESs and then clicks on RANK, the program applies the first EES, performs a simulation, saves the results, removes the EES, applies the next EES, and so forth until all the EESs have been applied and simulated. The program then ranks the results according to any of several desired criteria and displays the results. The whole process required only 10 minutes on a Pentium II 200.

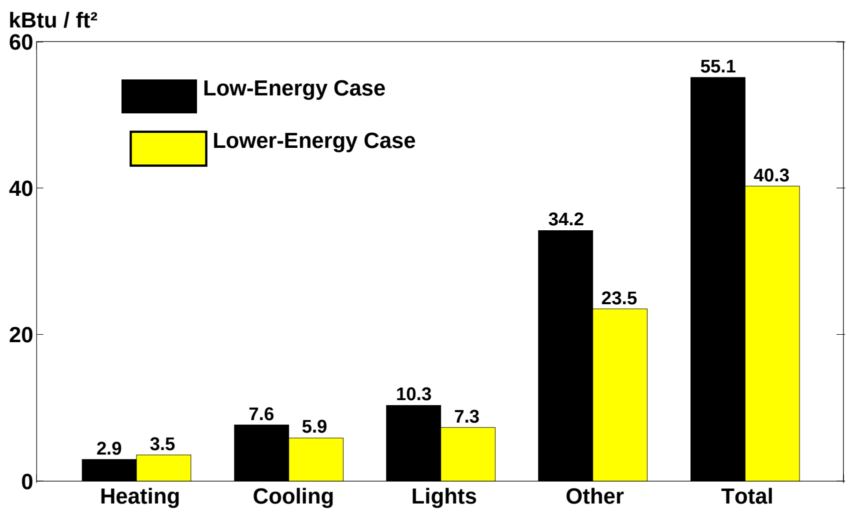
Note that the strategies are interactive. This means that one cannot simply add the savings due to individual strategies to get the total savings. Some strategies compete for the same energy, such as daylighting and energy-efficient lights. Other are complimentary; such as shading, passive solar heating, and thermal mass; in which case the savings can actually exceed the sum of the individual savings.

Another option in *ENERGY-10* is to use RANK subtractively. In this case the strategies are *omitted* one at a time instead of being *added* one at a time. This more clearly identifies the least effective strategies rather than the most effective strategies.

Up to this point, the results are for the first pair of shoeboxes that are created by AutoBuild using the defaults that have been set (the defaults used in this example are those originally set in the installation of *ENERGY-10*, but the user can easily change them to better represent typical practice or local codes and his or her preferred way of doing upgrades. The strategies used are the 12 that are automated in *ENERGY-10*.

It is possible to go beyond these 12 strategies, but this is done manually rather than by APPLY. For example, one can approximate the thermal benefit of an air-to-air heat exchanger by reducing the minimum occupied outside air by the efficiency of the air-to-air heat exchanger. Internal gains can be reduced to account for insulation of a hot water tank, more efficient office equipment, turning unneeded lights off at night,and a better lighting design. The example building was modified to reflect these three upgrades with the following results:

ANNUAL ENERGY USE



- Peak internal lights is reduced to 1.00 W/ft^2.to account for a better lighting design with up-down fixtures
- Inside lights are turned off when the building is unoccupied; outside lights are turned off during the day.
- Plug loads are reduced from 1.52 W/ft^2 to 1.00 W/ft^2.
- Minimum occupied outside air is reduced from 925 CFM to 292 CFM (to approximately account for a 70% efficient air-to-air heat exchanger).
- Hot water internal gains are reduced from 0.26 W/ft^2 to 0.20 W/ft^2 (insulated tank)

This is called a “lower energy case”. To make the change, the Bldg-1 description (the low energy case is copied to Bldg-1, then changes are made to Bldg-2, which is then simulated. Results are saved as a new variant.

The result is a savings of 27% compared with the low-energy case or 72% compared with the original reference case.

The interactions are subtle. HVAC capacities are reduced—cooling because of the decreased internal gains and heating because of the heat exchanger. Lighting is decreased. Cooling is reduced because of the decrease in internal gains. Heating is increased because of the decrease in internal gains and decreased because of the heat exchanger, resulting in a small net increase. Fan energy is reduced.

All of the above calculations can and should be done *in the pre-design phase*, before any thought is given to building form or geometry. Decisions can and should be made regarding:

- Proper choice of glazing.
- Proper choice of insulation.

Critical information has been obtained regarding:

- The relative benefit of a daylighting strategy.
- The relative benefit of increasing HVAC component efficiencies.
- The relative benefit of a shading strategy.
- The relative benefit of energy-efficient lights.
- The relative benefit of placing ducts inside the thermal envelope (to reduce duct-leakage effects).
- The desirability of adding internal thermal mass.
- The impact of reducing infiltration.

Of course, the exact energy and operating cost values will all be affected by changes in building geometry that take place during the design phase. The most affected are shading and daylighting. However, the go/no-go decisions regarding which strategies to include will, in almost every instance, *not change much as the geometry changes*. It is far easier to carry out these evaluations with the simple shoebox geometry than struggle with the much more complex geometry of most actual buildings. It is simply more efficient to do it early. Then the actual geometrical design can be evaluated to see the final effects.

Experience has shown repeatedly that the overall energy picture usually does not change much as the building goes through preliminary design as a result of changes in geometry.

To illustrate this, the 6500 ft^2 Savings & Loan example is re-evaluated using a very articulated geometry chosen to bring more daylight into the building. Area take-offs for this preliminary design, shown on the following page, were calculated. There are 7 wall orientations rather than 4. There are four roof planes rather than 1. The number of windows is increased from 45 to 50, with 80% located on the south and southeast, primarily in vertical clerestory sections.

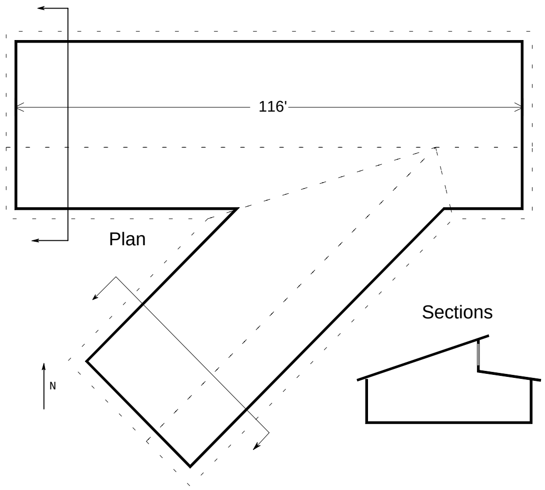
One change of great significance is the large overall reduction in HVAC capacity, going from the original reference case to the preliminary design. The AutoSize results, which only required about 2 seconds to compute prior to each simulation, are as follows:

	Reference Case	Preliminary Design
Rated Heating Capacity, kBtu/h	386	113
Rated Cooling Capacity, tons	27.5	12.6
Rated Air Flow, CFM	10740	5310

The latter two have the greatest effect on installed costs.

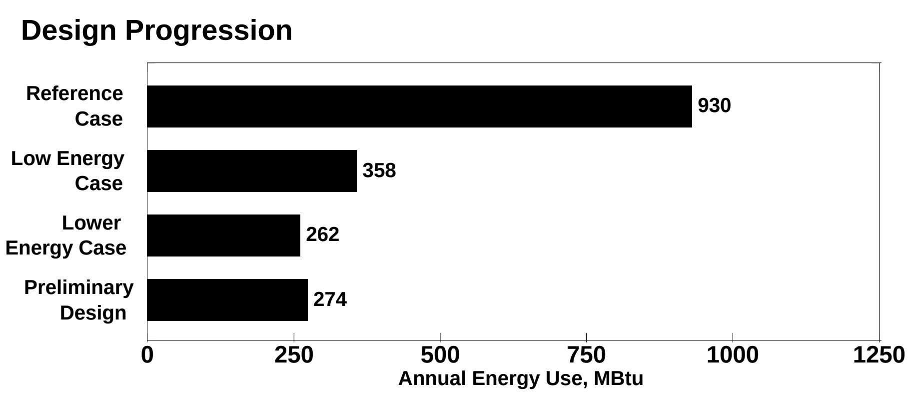
Experience in actual buildings has shown that these savings can very likely pay for the all the other upgrades.

The assumptions used for the AutoSize calculations are identical for all cases in this analysis. The oversizing factor is 1.2. The heating and cooling design-day temperatures and supply temperatures are the same. The decreases are a direct result of the reduced heating and cooling loads.



Preliminary design of the Columbia Savings & Loan. South and southeast-facing clerestories bring in daylight, which is diffused by internal baffles to illuminate the interior uniformly. Floor area is 6616 ft^2 Window area is increased from 1080 ft^2 to 1200 ft^2. Wall area is increased from 4279 ft^2 to 6596 ft^2. Roof area is increased 4%. This building is definitely *not* a shoe box.

The *ENERGY-10* energy analysis of the preliminary design shows only a small change compared to the Lower Energy Case shoe box despite major geometrical changes. Heating is increased 50% because wall surface area is greater; however, heating was small anyway. Cooling is decreased 7% by the better orientation of windows, despite the increased area. The KEEP function of *ENERGY-10* was used to show the design progression. Results from each step were "kept", and the results displayed, as shown below:



Similar results have been found in similar situations. Many processes that effect energy use are not greatly affected by the details of building geometry and there are often compensating effects.

In this building, the largest remaining component of energy use is internal gains due to plug loads. This single category accounts for \$0.33/ft^2 of the total \$0.63/ft^2 of annual energy cost.